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Experimental study of spatial and seasonal temperature characteristics of Jalingo metropolis

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ABSTRACT

The paper presents the results of studying the spatial and seasonal atmospheric temperature characteristics of Jalingo metropolis, Nigeria, with the aim of assessing seasonal temperature variations for thermal comfort planning. Temperature data for this study was collected across the local climate zones, otherwise known as thermal climate zones (TCZ), following the TZC classification of the area. Temperature data was collected for 30 days continuously and simultaneously across the TCZ. The collection of temperature data was done in the months of April and August 2021, and January 2022 – representing the dry season, the rainy season and the Harmattan period respectively. A Thermochron Ibutton sensor by Maxim Incorporation was used to collect temperature data, while the specific series used was DS1921. An improvised automated weather station was constructed to house the sensor. The result of the study indicates that air temperature varies considerably within Jalingo metropolis, as well as throughout the seasons, thus affecting human thermal comfort in the study area, as temperature is found to correlate well with both human morbidity and mortality, especially regarding cardiovascular diseases. The paper recommends increasing ventilation and nature-based solution to reduce high temperatures through tree planting in order to improve human thermal comfort in Jalingo metropolis area.

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1. Introduction

In the past century, the Earth's climate has warmed by approximately 0.6 °C, while the ecological responses to recent climate change are attracting increasing attention. Climate warming has a direct impact on land surface temperature (LST), thus speeding up the thaw of permafrost, which subsequently affects soil organic matter degradation, hydrology, and the carbon budget (Lawrence and Slater 2005; Zanobetti and Schwartz 2008; Zimov et al. 2006). Air temperature measurement is of great importance for epidemiological studies. Kloog et al. (2012) revealed that there is a correlation between variation of ambient minimum air temperature and human morbidity and mortality, especially with regard to cardiovascular diseases.

Knowledge of the current temperatures in all parts of the atmosphere is crucial for weather forecasting and thermal climate assessments in urban areas. Air temperature is one of the most sensitive indicators of the dynamical and physical processes in the atmosphere. It is affected by interactions between air and land or ocean, by the radiation received from the Sun and emitted by the atmosphere and the Earth's surface, by chemical interactions (particularly in the upper atmosphere), by changes in the state of water from gas to liquid and ice, and vice versa, and by upward and downward motion of energy (Zhou et al. 2020).

Over the years, air temperature in Jalingo metropolis area was observed to vary considerably within the city. However, that variation has not been scientifically investigated and documented so as to be used in reference documents. The variation in temperature affects thermal comfort in the area, thus posing difficulties to town planners and architects. This study, therefore, analyzes temperature characteristics of Jalingo metropolis for better understanding of spatial and seasonal variations of air temperature in the study area, so that thermal comfort decisions and assessments can be made by planners and architects working in the study area.

Atmospheric temperature data is used for monitoring worldwide temperature changes, identifying correlations between atmospheric parameters and climatic behavior, and validating global models of the atmosphere. Temperature data may also be used for computing the upper level wind structure, which, in turn, can aid the prediction of strong winds at the surface, and warn about possible storm surges of the sea level in coastal areas.

The temperature at any particular place is influenced by a number of factors such as latitude, season, altitude and proximity to ocean, time of day, wind direction and present weather conditions. The last three of those define the variations in temperature over short periods of time. Intensification of contemporary global warming in recent decades, along with the enhancement of the greenhouse effect (He et al. 2019), have caused a significant rise of interest in the year-to-year and decadal-scale climate variability.

2. Materials and methods

2.1. Study area

Taraba State is situated between 6°30’ 00”N to the south and 9°36’ 00”N to the north. Jalingo metropolis, on the other hand, lies between 8°52’ 00”N and 8°56’00”N, and between 11°19’ 00”E and 11°24’00”E (Fig. 1). The metropolis consists of the whole of Jalingo Local Government Area (LGA), as well as parts of Ardo-Kola LGA. The part of Ardo-Kola LGA falling within the metropolis is where the Advanced Teachers College (ATC) and the Taraba State University are situated.

The rainy season in Jalingo metropolis spans from April through October, with a mean annual precipitation amount between 750 mm to 880 mm (Adebayo 2001). Air temperatures in Jalingo vary between 29°C and 37°C, with an average mean of 32°C in the months of August and September. The coldest months are December and January, which is as a result of desiccated air (cold and dry wind) coming from the Sahara Desert. The warmest months are April and May. The climate of Jalingo metropolis is influenced by two dominant trade winds, namely the Southwest trade wind and the Northeast trade wind.

Jalingo metropolis lies between 196.9 m and 914 m above sea level. It is situated on a gently rolling slope that leads to the great plains of Muri. To the south of Jalingo metropolis the land raises to about 914 m – an altitude which modifies the micro-climate of Jalingo. This peak forms the watershed of the Lamurde River – the main river draining Jalingo metropolis, together with other streams which represent tributaries of the Benue River in that area. To the north of the city there are a number of hills and rocky outcrops, whose elevation varies between 323 m and 349 m (Zemba et al. 2019).

There has been a population number increase in Jalingo metropolis, especially after the city was declared the state capital of Taraba state in 1991, resulting in an influx of people looking for employment opportunities provided by the new status of the city. The population number increased by 35% (Zemba 2012). Consequently, there has been rapid urbanization with significant changes in land-

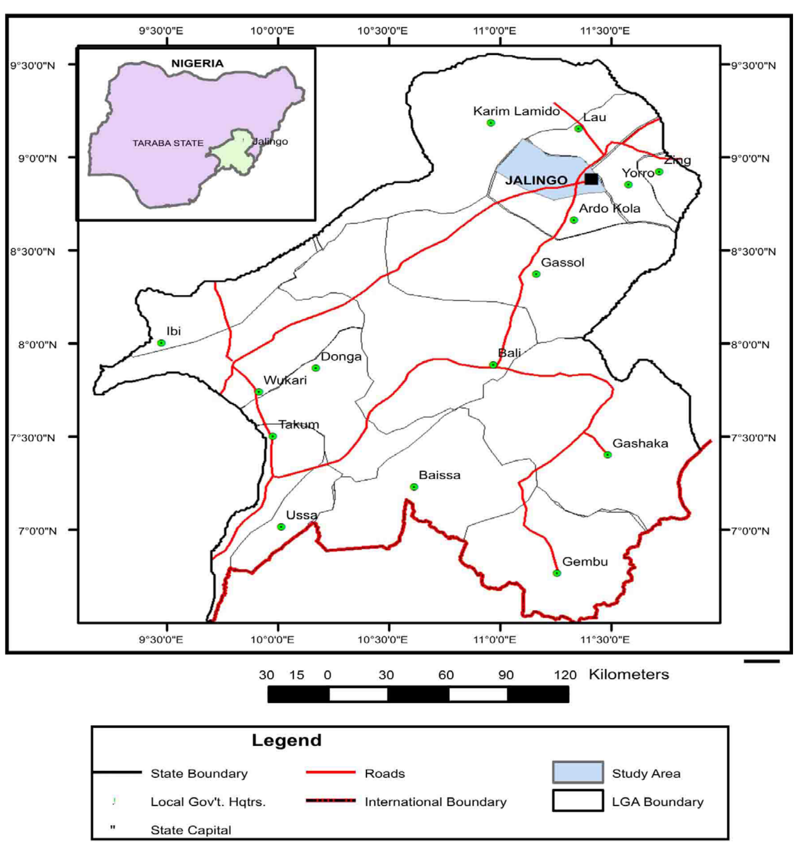


Figure 1. Map of the study area.

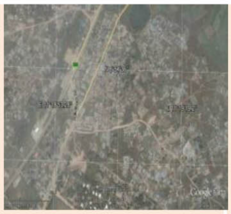
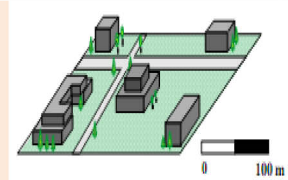
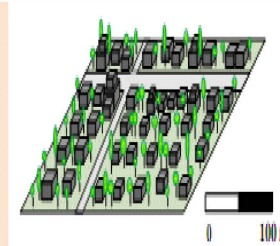
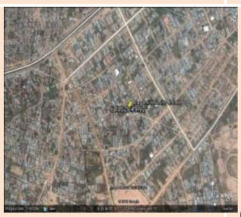
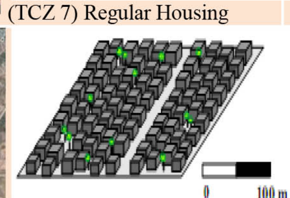
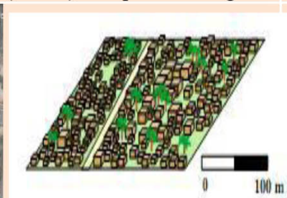
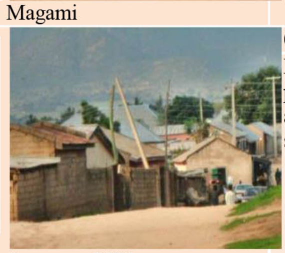
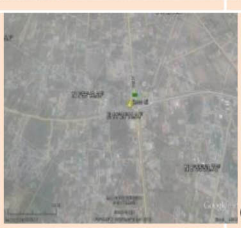
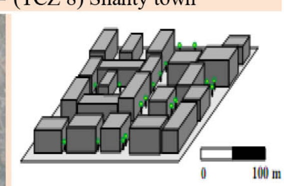
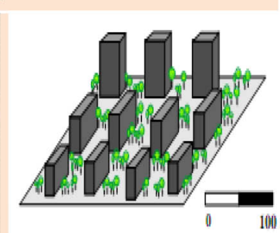
Site	Satellite view	Thermal climate zone (TCZ)	Site Photo	Zones properties
Site1 (T.S.U Jalingo 8°54'15.14"N 11°19'04.03"E Altitude= 204.81m		 (TCZ 9) Open space	 T.S.U. Jalingo	H/W %built[2] QF[3] 1.75 30-40 5-10 Large, widely set, mid-rise buildings in an open place. Buildings vary in size, distribution, height with abundant vegetation.
Site2 (Tech.mile six) 8°57'53.38"N 11°22'22.93"E Altitude= 224.1m		 (TCZ 7) Regular Housing	 Technobat	0.70 40-70 10-15 Low-rise buildings that are detached. And the buildings separated by yards, and set along medium width streets. Light traffic flow and uniform in design.
Site3 (Magami) 8°54'36.00"N 11°20'49.92"E Altitude= 196.9m		 (TCZ 3) Compact Housing	 Magami	1.30 >70 20-30 Buildings densely packed and are low rise. Light traffic flow. Construction materials uniformly arranged.
Site4 (Anguwan N.T 8°53'20.35"N 11°22'23.12"E Altitude= 226.8m		 (TCZ 8) Shanty town	 Anguwan NTA	0.65 >65 >5 Buildings small and fragile, densely packed, separated by narrow streets and alleyways. Mostly unpaved, swampy compacted surfaces.
Site5 (Roadblock) 8°56'12.56"N 11°20'16.82"E Altitude= 211.8m		 (TCZ 2) Old core	 Road block	1.20 >80 30-50 Buildings are often large and dense, attached or closet, homogeneous in character with wide streets. Heavy traffic flow.
Site6 (Comm.quarte 8°54'25.65"N 11°23'30.56"E Altitude= 213.4m		 (TCZ 5) Block housing	 Commissioners Quarters (Comm.Q)	1.60 <80 20-35 Medium high-rise buildings, uniform in design (height and width), of solid construction. Abundance of vegetation and open space in between buildings with light traffic flow.

Figure 2. Thermal Climate Zones Typology in Jalingo. Adopted from Asa et al. (2017)

use and land-cover, as well as increased anthropogenic activities that have affected the micro-climate of Jalingo. Zemba (2012) observed a substantial increase in the built-up area of Jalingo metropolis, which increased by 1115 % in the period between 1991 and 2009.

2.2. Experimental investigation

Experiments were carried out in different locations within Jalingo metropolis, in order to collect temperature data for this study. Temperature data was collected in April 2021 (representing the dry season), August 2021 (representing the wet season) and January 2022 (representing the Harmattan period). Attention has been paid to the different types of land-use with their different anthropogenic activities and interactions – different types of land-use generate, store and release heat differently, thereby resulting in temperature variations within the urban environment. The study adopted the land-use/land-cover classification method by Stewart and Oke (2010), known as the thermal climate zones (TCZ) classification.

Thermal climate zones are regions of relatively uniform surface air temperature distribution across a horizontal scale of 10^2 m to 10^4 m (Stewart and Oke 2010). Jalingo metropolis – the study area of this experimental research – was classified into thermal climate zones by Asa et al. (2017) (Fig 2). It is that thermal climate zones classification which was adopted for collecting temperature data for this study.

Temperatures were measured using the digital Thermochron Ibutton sensor by Maxim Incorporation in each of the thermal climate zones identified by Asa et al. (2017), following the WMO guidelines for data acquisition and instrumentation in urban areas.

The Thermochron Ibutton sensor was mounted on an electric pole (about 3-meter high, which is the average roof level in the area), 10 meters away from the nearest obstacle (houses/trees). The device was programmed to continuously log in data at a 10-minute interval in all the TCZs simultaneously. The data was processed at the end of the exposure period, using the interface kit. The exposure period was 30 days at each phase of the research data collection:

1. April 2021 – representing the dry season.
2. August 2021 – representing the wet season
3. January 2022 – representing the Harmattan period

Descriptive statistics were used to describe and analyze the temperature characteristics. The descriptive statistics include mean air temperatures, graphs (linear graphs and histograms) for pictorial representation of diurnal temperature range, as well as other characteristics. Hourly temperature data was analyzed so as to assess the hourly temperature characteristics of the area. Furthermore, temperature data was sampled at sunrise, mid-day and sunset so as to assess the temperature characteristics during those times of the day.

3. Results and discussion

The collected temperature data was summarized and then standardized to hourly temperatures, range, minimum, maximum, sum, mean and standard deviations, and presented in Table 1.

The diurnal temperatures for all sites were examined – the variations and characteristics of sunrise, sunset and mid-day temperatures were examined for adequate and proper analysis. The result is presented in Fig 3.

Table 1. Mean hourly temperature characteristics of the study area.

	Number of hours	Range	Minimum	Maximum	Sum	Mean	Std. Deviation
TSU	24	5.93	26.20	32.13	699.34	29.1392	1.77053
TECNO	24	8.17	26.00	34.17	729.23	30.3846	2.46989
MAGAMI	24	7.96	27.00	34.96	730.88	30.4533	2.69261
NTA	24	8.60	27.06	35.66	752.27	31.3446	2.50918
JEZCO	24	7.78	27.02	34.80	745.76	31.0733	2.35330
COM.Q	24	5.91	26.14	32.05	706.32	29.4300	1.83356
Valid N	24						

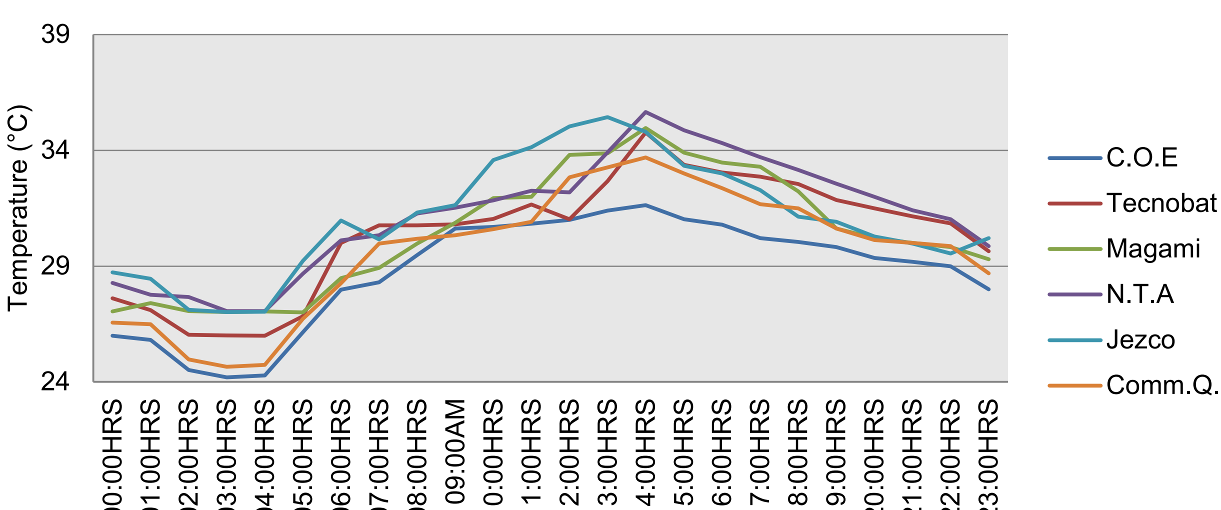


Figure 3. Mean hourly temperature variations.

3.1. Mean hourly temperature characteristics

The results presented in Fig. 3 reveal that during the study period the sites follow the same pattern most of the time, except for TSU and Comm.Q which deviate from the early morning hours (between 2:00 hrs to 5:00 hrs local time). Sites 1 (TSU) and 6 (Comm.Q) further deviate from the other sites around mid-day (12:00 hrs local time) and trail behind at 18:00 hrs local time. This result corresponds with findings by Nduka and Abdulhamid (2009) in Onitsha, south-eastern Nigeria, who used a similar method to conduct similar research.

The results presented in Table 1 reveal that the maximum temperature was attained at site 4 (Anguwan NTA – 35.66°C) at 14:00 hrs local time. This result also corresponds with other studies in the tropical regions which also show that maximum temperatures were attained by mid-day around 14:00 hrs (Balogun et al. 2010; Nduka and Abdulhamid 2009; Ibrahim et al. 2010). However, those were outside the tropics and the result does not correspond with findings such as those of Arnfield (2003) and Oke (1987). Meanwhile, the lowest temperature was recorded at site 1 (TSU, Jalingo – 24.20°C).

The maximum temperature was recorded two hours after mid-day (12:00 hrs at noon), signifying the peak of warming period and the end of daytime warming period, while the lowest temperature was recorded an hour before sunrise, signifying the peak period of cooling (the end-of-night time cooling and the beginning of the daylight warming). The differences in temperatures observed at these sites could be a result of the differences in their surface cover and the level of anthropogenic activities within these sites. For example, site 4 (NTA) and site 5 (Road block) exhibit higher surface roughness, low H/W ratio and higher anthropogenic activities – all factors contributing to rural-urban temperature difference (Oke 1987; Chow and Roth 2006).

The mean hourly temperature ranges as seen in the Table 2 show that site 4 (NTA) had the highest (8.60°C), while site 6 (Comm.Q) had the lowest temperature range (5.91°C). These two sites have different surface morphology – NTA represents a slum, while Comm.Q is a low-density residential area with high-rise buildings; the surface morphology affects the ability of the sites to generate, retain and radiate heat.

3.2. Mean sunrise temperature characteristics

The analysis of sunrise temperature characteristics was based on temperatures measured at 9:00 hrs a.m. local time, in order to show the relative effects of gradual temperature warming after sunrise in the study area. The time was chosen based on previous studies (Chow and Roth 2006; Balogun et al. 2010; Nduka and Abdulhamid 2009; Zemba 2003) where different time series had been chosen. The result is presented in Fig. 4.

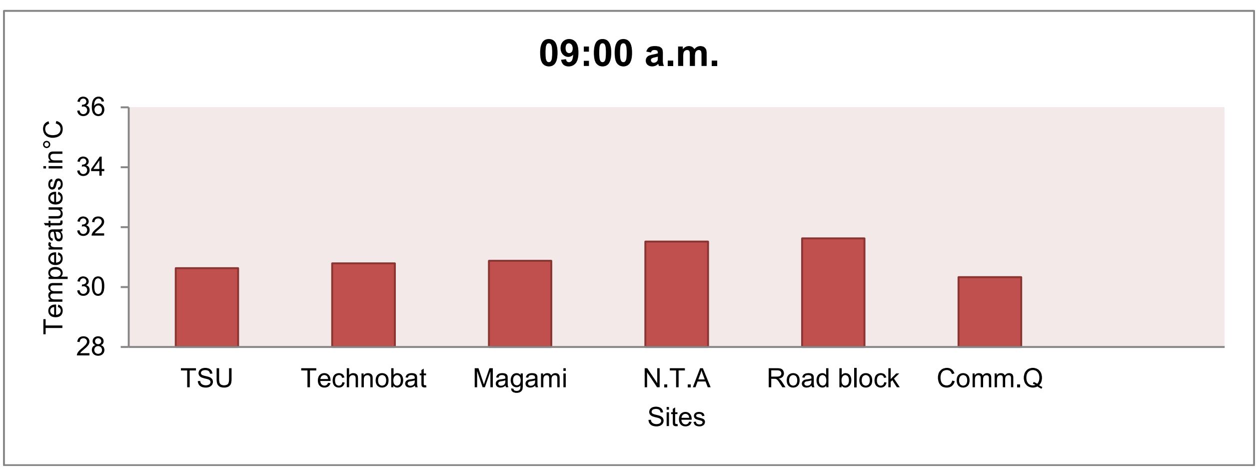


Figure 4. Sunrise temperature at 9:00 hrs.

The maximum temperature measured at 9:00 hrs was recorded at site 4 (NTA) – 31.63°C, while the lowest temperature was recorded at site 6 (Comm.Q) – 30.34°C. The temperature range for this period was 1.29°C, which could be attributed to the canyon geometry, surface geometry, morphology, and the level of anthropogenic activities within the study area at that time of the day. As mentioned earlier, site 4 (NTA) is a slum, with most of the roughness element comprising of shanty houses and very little vegetation with low H/W ratio. The surface is swampy during the rainy season, thus keeping the ambient air temperature at the site low during that season. Site 6 (Comm.Q), on the other hand, is a low-density residential area with higher H/W ratio (compared to that of site 4 – NTA) of 1.60. The roughness element of this area includes concrete buildings and vegetation, while the roads are covered with asphalt.

Sunrise temperature was observed to be higher compared to site 6 (Comm.Q) at site 1 (TSU) as well. This is the result of variations in the canyon geometry – site 1 (TSU), it has a higher H/W ratio compared to that of site 6 (Comm.Q), meaning that TSU will receive higher insulation because of the larger area open to incoming solar radiation, thus warming up the ambient air more than in the case of site 6.

3.3. Mean mid-day temperature characteristics

The analysis of mid-day temperature characteristics was performed at 14:00 h local time, two hours after mid-day. The analysis was made in order to assess the relative effect that the mid-day sun has on temperatures as a result of temperature lag and anthropogenic activities in the study area. The result is presented in Fig. 5.

The result shows that the maximum temperature was recorded at site 4 (NTA) – 35.66°C, while the minimum temperature was attained at site 1 (TSU) – 32.13°C. These stations' values have a range of 4.03°C – similar to the one measured in other studies in Nigeria (Balogun et al. 2010; Xu et al. 2013).

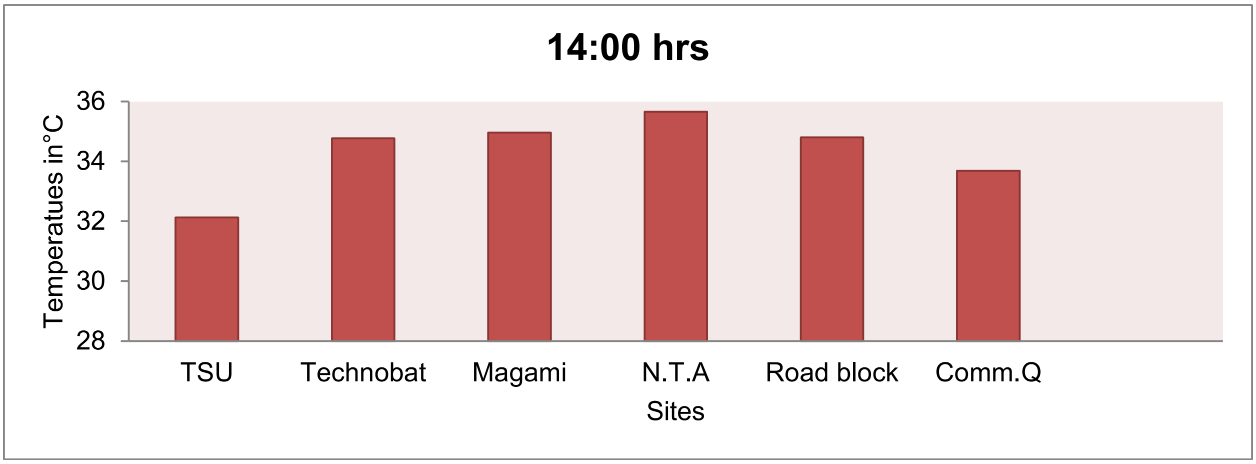


Figure 5. Mean mid-day temperature characteristic at 14:00 hrs.

Sites one 1 (TSU) and 4 (NTA) have diverse morphologies and surface cover – NTA is a slum with high population density, comprised of low surface albedo, which makes the surface of the site generate and retain heat. The site is also heavily built-up with little vegetation and a higher intensity of anthropogenic activities. TSU is located away from the urban center, it is surrounded by lots of vegetation and widely spaced buildings, with a lower intensity of anthropogenic activity. The amount of vegetation in the site and the low intensity of human activities do not allow a significant temperature buildup. On the other hand, the higher H/W ratio allows for early heating of the area as higher insulation is received earlier. However, early cooling is also experienced as long-wave radiation escapes back into space easily because of the large open spaces, which allows free circulation of wind.

3.4. Mean sunset temperature characteristics

The sunset temperature was sampled at 20:00 hrs local time, which is two hours after sunset at 18:00 h. The analysis was carried out so as to assess the nature of cooling and heat loss within the study area. The result is presented in Fig. 6 below.

The result shows that the highest temperature was recorded at site 4 (32°C), while the lowest temperature was measured at site 1 (29.35°C). The temperature range for this period is 2.65°C. The difference observed can be attributed to the surface characteristics, anthropogenic heat sources, canyon geometry and the properties of the building materials within the sites.

Site 1 (TSU) is an open ground with widely spaced buildings and abundant vegetation, which enables the generation of heat faster during the day after receiving insulation, and it likewise releases heat faster at sunset, hence the lowest temperature recorded at that site. However, site 5 has the ability to generate more heat due to high vehicular traffic of diesel-powered engines and high anthropogenic activities during the day, which results in accumulation of heat. At sunset, due to the surface morphology of the site where natural surfaces were replaced by artificial surfaces (such as asphalt), coupled with crowded structures (which have the ability to reduced wind circulation and thus encourage heat retention), consequently account for higher temperatures recorded at the site during the sampled time of the day.

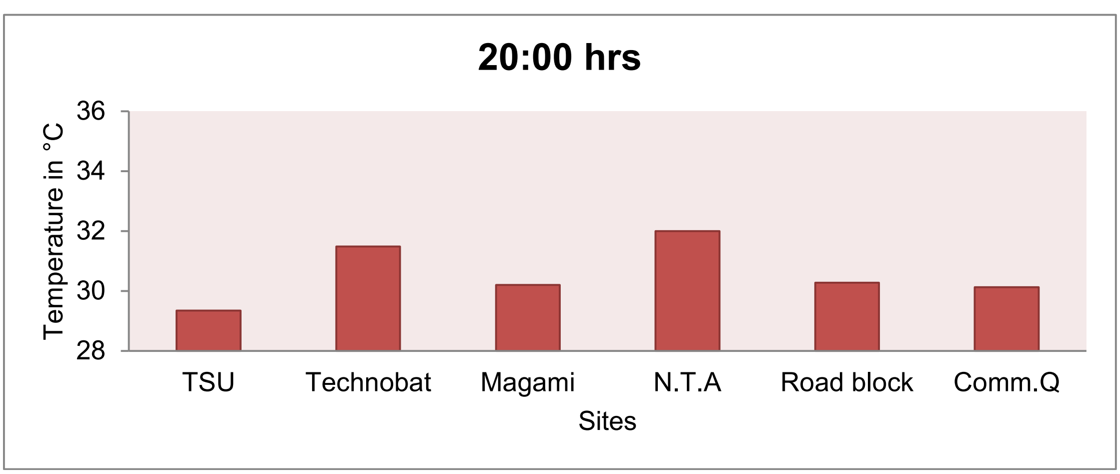


Figure 6. Mean temperature characteristic at sunset (20:00 hrs).

4. Conclusion

The analysis of air temperature characteristics of Jalingo metropolis confirmed certain influences of the urban area on air temperature, demonstrating that different areas within the same city may have significant variations in air temperatures. A temperature range of 5.7°C was observed within the study area, indicating that temperature variations related to distinct land-use types is eminent. Also, the study revealed that temperature warming and cooling rates and times vary within the study area. Therefore, we need to further investigate warming and cooling rates in the area in order to understand temperature dynamics in Jalingo metropolis. These observations may have important implications for urban planners and architects who are dealing with the effects which planning (and type of buildings) might have on the urban climate. Though there are variations across the TCZs and throughout the seasons, temperature cooling in the study area generally begins after 14:00 hrs local time, while general warming starts at 09:00 hrs local time. Urban planners and architects should consider the results of this study when planning and designing buildings, in order to achieve a thermal comfort improvement in the area.

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Conflict of interest

The authors have declared that no competing interests exist.

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